

High Energy Cosmic Tau Neutrinos*

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I discuss the possibility of production of high energy cosmic tau neutrinos ($E \geq 10^6$ GeV) in an astrophysical site and study some of the effects of neutrino mixing on their subsequent propagation. I also discuss the prospects for observations of these high energy cosmic tau neutrinos through double shower events in new km² surface area under water/ice neutrino telescopes.

1. INTRODUCTION

In this contribution i discuss the possibility of production of high energy cosmic tau neutrinos ($E \geq 10^6$ GeV) in cores of Active Galactic Nuclei (AGN) originating from proton acceleration. The effects of three flavour neutrino mixing on this high energy cosmic tau neutrino flux and the prospects for its observations through double shower events [1].

In addition to AGNs, high energy cosmic tau neutrinos may also be produced in several currently envisaged other cosmologically distant astrophysical sources [2]. For some possible effects of neutrino mixing other than the flavour one on high energy cosmic tau neutrino flux, see [3]. For prospects of observations of high energy cosmic tau neutrinos other than the double shower technique, see [4]. The present study is particularly useful as several under water/ice high energy neutrino telescopes are now at their rather advanced stages of development and deployment [5].

I start in Section 2 with a brief description of possibility of production of high energy cosmic tau neutrinos relative to electron and muon neutrinos and discuss in some detail the effect of three flavour neutrino mixing on their subsequent propagation and further discuss the prospects for their detection through double shower events. In Section 3, i summarize the results.

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2. HIGH ENERGY COSMIC TAU NEUTRINOS

2.1. Production

High energy cosmic tau neutrinos may either mainly be produced in $p\gamma$ or in pp collisions in a cosmologically distant environment.

In $p\gamma$ collisions, high energy ν_e and ν_μ are mainly produced through the resonant reaction $p + \gamma \rightarrow \Delta^+ \rightarrow n + \pi^+$. The same collisions will give rise to a greatly suppressed high energy ν_τ (and $\bar{\nu}_\tau$) flux ($\nu_\tau/\nu_{e,\mu} < 10^{-5}$) mainly through the reaction $p + \gamma \rightarrow D_S^+ + \Lambda^0 + \bar{D}^0$. In pp collisions, the ν_τ flux may be obtained through $p + p \rightarrow D_S^+ + X$. The relatively small cross-section for D_S^+ production together with the low branching ratio into ν_τ implies that the ν_τ flux in pp collisions is also suppressed up to 5 orders of magnitude relative to ν_e and/or ν_μ fluxes.

Thus, both in $p\gamma$ and in pp collisions, the intrinsically produced tau neutrino flux is expected to be rather quite small, typically a factor less than 10^{-5} relative to electron and muon neutrino fluxes [6].

2.2. Propagation

Matter effects on vacuum neutrino flavour oscillations are relevant if $G_F \rho / m_N \sim \delta m^2 / 2E$. Using ρ given in Ref. [7], it follows that matter effects are absent for $\delta m^2 \geq \mathcal{O}(10^{-10})$ eV². Matter effects are not expected to be important in the neutrino production regions around AGN and will not be further discussed here.

In the framework of three flavour analysis, the flavour precession probability from α to β neutrino flavour is [8]

$$P_{\alpha\beta} = \sum_{i=1}^3 |U_{\alpha i}|^2 |U_{\beta i}|^2 + \sum_{i \neq j} U_{\alpha i} U_{\beta i}^* U_{\alpha j}^* U_{\beta j} \cos\left(\frac{2\pi L}{l_{ij}}\right), \quad (1)$$

where $\alpha, \beta = e, \mu$, or τ . U is the 3×3 MNS mixing matrix and will be used in usual notation with the standard parameterization for vanishing θ_{13} and CP violating phase [9]. In Eq. (1), $l_{ij} \simeq 4\pi E / \delta m_{ij}^2$ with $\delta m_{ij}^2 = |m_i^2 - m_j^2|$ and L is the distance between the source and the detector.

Currently, the atmospheric muon and solar electron neutrino deficits can be explained with oscillations among three active neutrinos [10]. For this, typically, $\delta m^2 \sim \mathcal{O}(10^{-3})$ eV² and $\sin^2 2\theta \sim \mathcal{O}(1)$ for the explanation of atmospheric muon neutrino deficit, whereas for the explanation of solar electron neutrino deficit, we may have $\delta m^2 \sim \mathcal{O}(10^{-10})$ eV² and $\sin^2 2\theta \sim \mathcal{O}(1)$ [just so solution] or $\delta m^2 \sim \mathcal{O}(10^{-5})$ eV² and $\sin^2 2\theta \sim \mathcal{O}(10^{-2})$ [SMA (MSW)] or $\delta m^2 \sim \mathcal{O}(10^{-5})$ eV² and $\sin^2 2\theta \sim \mathcal{O}(1)$ [LMA (MSW)].

In the above explanations, the total range of δm^2 is $10^{-10} \leq \delta m^2 / \text{eV}^2 \leq 10^{-3}$ irrespective of neutrino flavour. The typical energy span relevant for possible flavour identification for high energy cosmic neutrinos is $2 \cdot 10^6 \leq E / \text{GeV} \leq 2 \cdot 10^7$ in which currently the neutrino flux from cores of AGNs dominate. Taking a typical distance between the AGN and our galaxy as $L \sim 100$ Mpc (where $1 \text{ pc} \sim 3 \cdot 10^{16} \text{ m}$), the cos term in Eq. (1) vanishes and so Eq. (1) reduces to

$$\langle P_{\alpha\beta} \rangle \simeq \sum_{i=1}^3 |U_{\alpha i}|^2 |U_{\beta i}|^2. \quad (2)$$

It is assumed here that no relatively dense objects exist between the AGN and the earth so as to effect significantly this oscillations pattern. The $\langle P_{\alpha\beta} \rangle$ in Eq. (2) is independent of not only δm^2 but also E .

Let me denote by F_α^0 , the intrinsic high energy cosmic neutrino fluxes. For simplicity, i take their

ratios as $F_e^0 : F_\mu^0 : F_\tau^0 = 1 : 2 : 0$. In order to estimate the final flux ratios on earth, let me introduce a 3×3 matrix of vacuum flavour precession probabilities such that

$$F_\alpha = \sum_\beta \langle P_{\alpha\beta} \rangle F_\beta^0. \quad (3)$$

The explicit form for the matrix $\langle P \rangle$ in case of just so flavour oscillations as solution to solar neutrino problem along with the solution to atmospheric neutrino deficit in terms of ν_μ to ν_τ oscillations with maximal depth is

$$\langle P \rangle = \begin{pmatrix} 1/2 & 1/4 & 1/4 \\ 1/4 & 3/8 & 3/8 \\ 1/4 & 3/8 & 3/8 \end{pmatrix}. \quad (4)$$

Using Eq. (4) and Eq. (3), we note that $F_e : F_\mu : F_\tau = 1 : 1 : 1$ at the level of F_e^0 . Also, the unitarity conditions for $\langle P_{\alpha\beta} \rangle$ are satisfied. The same flux ratio is obtained in remaining two cases. Thus, essentially independent of the oscillation solution for solar neutrino problem, i have $F_e : F_\mu : F_\tau = 1 : 1 : 1$. This provides some prospects for possible detection of high energy cosmic tau neutrinos.

2.3. Prospects for detection

The down ward going high energy cosmic tau neutrinos reaching close to the surface of the detector may undergo a charged current deep inelastic scattering with nuclei inside/near the detector and produce a tau lepton in addition to a hadronic shower. This tau lepton traverses a distance, on average proportional to its energy, before it decays back into a tau neutrino and a second shower most often induced by decay hadrons. The second shower is expected to carry about twice as much energy as the first and such double shower signals are commonly referred to as a double bangs. As tau leptons are not expected to have further relevant interactions (with high energy loss) in their decay time scale, the two showers should be separated by a clean μ -like track [1,11].

The calculation of down ward going contained but separable double shower event rate for a typical km² surface area under water/ice neutrino

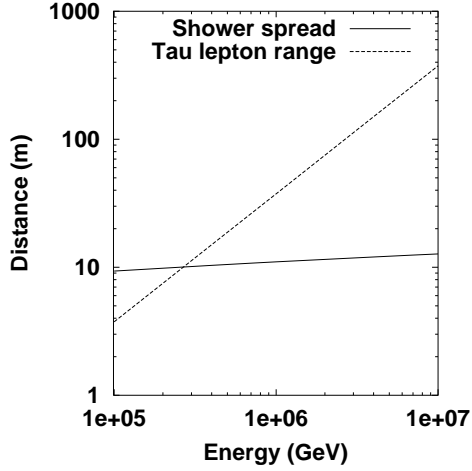


Figure 1. Comparison of the tau lepton range and the shower length of the first shower in ice/water.

telescope can be carried out by replacing the muon range expression with the tauon one and then subtracting it from the linear size of a typical high energy neutrino telescope in the event rate formula while using the expected ν_τ flux spectrum given by Eq. (3). Here, I confine myself by mentioning that the expected number of contained but separable double showers induced by down ward going high energy cosmic tau neutrinos for $E \sim 2 \cdot 10^6$ GeV may be $\sim \mathcal{O}(10)/\text{yr}\cdot\text{sr}$, essentially irrespective of solution of solar neutrino problem, if one uses the F_e^0 from Ref. [7] as an example. At this energy, the two showers initiated by the down ward going high energy cosmic tau neutrinos are well separated (see Fig. 1) such that the amplitude of the second shower is essentially 2 times the first shower.

3. CONCLUSIONS

1. Intrinsically, the flux of high energy cosmic tau neutrinos is quite small, typically being $F_\tau^0/F_{e,\mu}^0 < 10^{-5}$ from, for instance, cosmologically distant cores of Active Galactic Nuclei.

2. Because of vacuum neutrino flavour oscillations, this ratio can be greatly enhanced. In the

context of three flavour neutrino mixing scheme which can accommodate the oscillation solutions to solar and atmospheric neutrino deficits, the final flux ratio of high energy cosmic neutrinos on earth is $F_e \sim F_\mu \sim F_\tau \sim F_e^0$.

3. This enhancement in high energy cosmic tau neutrino flux may lead to the possibility of its detection in km^2 surface area under water/ice high energy neutrino telescopes. For $2 \cdot 10^6 \leq E/\text{GeV} \leq 2 \cdot 10^7$, the down ward going high energy cosmic tau neutrinos may produce a double shower signature because of charged current deep inelastic scattering followed by a subsequent hadronic decay of associated tau lepton.

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